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Performances of Palm Oil Fuel Ash Cement Based Aerated Concrete in Acidic and Sulphate Environments

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ABSTRACT

Malaysia as the world's largest exporter of palm oil has been facing problem in disposing palm oil fuel ash, a by-product of palm oil mill since many years ago. The discovery made by researchers of Universiti Teknologi Malaysia last century in revealing the potential of this waste as a partial cement replacement in normal concrete has stem more efforts towards studying the possibility of using it in lightweight concrete production. Currently, investigation conducted proved that this material also can be integrated as a partial cement replacement material producing lightweight concrete known as Palm oil fuel ash cement based aerated concrete which possess adequate strength with lower density than OPC aerated concrete. This paper illustrates the durability aspect of this new agro blended cement based aerated concrete in terms of resistance towards aggressive chemicals such as acid and sulphate. Aerated concrete cube consisting 20% palm oil fuel ash and control specimen with 100% OPC were cast and then subjected to water curing for 28 days before immersed in the hydrochloric solution prepared using 0.3% hydrochloric acid having 99% concentration. The pH of the solution was controlled to about 2 throughout the immersion period of 1800 hours. The durability performance of the cubes involved the measurement of weight loss at a different period of immersion in the solution. In order to study the performance of this material in sulphate environment, a set of control specimen and another one consisting the same proportion of POFA were prepared before water cured for 28 days. Sulphate resistance of the binders was evaluated by measuring the expansion of mortar bars after immersion in 10% sodium sulphate solution for the period of 6 months. Finding will be discussing the performance of POFA cement based aerated concrete in both acidic and sulphate environments.

KEYWORDS

Palm oil fuel ash, Partial cement replacement, POFA cement based aerated concrete, Acid resistance, Sulphate resistance

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1 INTRODUCTION

Concrete, the oldest manufactured construction material used in building work all around the world has occupied a unique place with its unquestionable application use in the construction industry. This construction material has been subjected to endless research throughout the century thus resulting in fruitful findings which successfully lead to creation of value added concrete materials fulfilling to customers requirement. The availability of high-tech telecommunication network system nowadays, has indubitably assist active knowledge dissemination specifically among researchers involved in concrete research area, resulting in sharing of fascinating ideas such as converting worthless industrial or agricultural by-product available to be partially cement or sand substitute constituent. Implementation of unique ideas has results in discovery of new type of environmental friendly concrete with lower cost than the existing concrete or able to offer more benefits than the original one.

In Malaysia, aerated concrete which began to capture the interest of local contractors due to its lightness and easier handling during building process has also subjected to innovation process. In early 21st century, Faculty of Civil Engineering from Universiti Teknologi Malaysia has become the pioneer in the country attempting to integrate waste material in gas concrete production which well known as aerated concrete. The study on utilization of waste as partial constituent in aerated concrete started off with Arreshvhina [2002] whom integrated slag, a industrial waste as cement replacement and then followed by Mat Yahaya [2003] whom partially substituted sand partially with agriculture ash. The current researcher, Abdullah [2006a] has incorporated palm oil fuel ash as partial cement replacement successfully producing POFA cement based aerated concrete possessing satisfying strength. This approach is one of the effort to make use of the palm oil fuel ash, a by-product of palm oil mill that is generated abundantly in increasing volume throughout the year since Malaysian palm oil industry continue to grow in order to meet the customers demand. This achievement will have the double advantage towards palm oil mill whereby development of this material could increase the palm oil industry earnings and also a means of disposing the waste.

Glancing through on the discovery of POFA as a alternative constituent for cement production, Hussin & Abdul Awal [1996] has successfully manage to incorporate palm oil fuel ash as partial cement replacement for normal concrete enhancing the strength and durability of the new modified material known as POFA concrete. Then, usage of this material was broaden to other types of concrete when Sata, Jaturapitakkul and Kiattikomol [2004] successfully integrated a very finely ground POFA as partial cement replacement to produce high-strength concrete. Succeeding the findings, Faculty of Civil Engineering again discovered that it is possible to add palm oil fuel ash up to 30% as partial cement replacement in a type of concrete categorized as lightweight concrete known as POFA cement based aerated concrete [Abdullah et.al 2006b]. Though, few properties of this material has been looked into [Abdullah et.al 2006a, Abdullah et.al, 2006c, Abdullah et.al, 2006d] but durability aspect of this material still silent and this issue will be discussed in this paper.

2 MATERIALS AND EXPERIMENTAL PROGRAMME

2.1 Materials

Materials used in this study consisted of ordinary Portland cement, fine sand, POFA, aluminium powder, superplasticizer and water. The fine sand was local river sand that has been oven dried at the temperature of 110ºC for 24 hours and then sieved before stored in airtight container. Aluminium powder which is a gas foaming agent and a powder form superplasticizer was also employed in all aerated concrete mixtures. The POFA used is a by-product obtained from burning the remaining of extracted palm oil fibers and shells from a palm oil mill owned by Yayasan Pembangunan Johor which is located in State of Johor. The collected ashes were dried in the oven at the temperature of 110ºC ± 5 for 24 hours to remove moisture in it before sieved and ground until 99% of the ashes passes 45μm sieve during wet sieve test. A single batch of ordinary Portland cement (OPC) classed ASTM Type 1 was used throughout the experiment. Both chemical compositions of the OPC and POFA used in this work are shown in Table 1.

Table 1. Chemical compositions of ordinary Portland cement and palm oil fuel ash.

Chemical Composition	*OPC (%)*	*POFA (%)*
Silicon Dioxide (SiO_2)	**28.2**	**53.82**
Aluminium Oxide (AL_2O_3)	**4.9**	**5.66**
Ferric Oxide (Fe_2O_3)	**2.5**	**4.54**
Calcium Oxide (CaO)	**50.4**	**4.24**
Magnesium Oxide (MgO)	**3.1**	**3.19**
Sodium Oxide (Na_2O)	**0.2**	**0.1**
Potassium Oxide (K_2O)	**0.4**	**4.47**
Sulphur Oxide (SO_3)	**2.3**	**2.25**
Phosporus Oxide (P_2O_2)	**<0.9**	**3.01**
Loss On Ignition (LOI)	**2.4**	**10.49**

2.2 Test For Acid Resistance

Aerated concrete cube specimens (70.6x70.6x70.6mm) having a mix proportion of 1:1 for cement and fine sand by weight with fixed amount of aluminium powder and superplasticizer were cast. Another set of specimen with ash was also prepared in a similar way where OPC was replaced, mass for mass, by 20% POFA. The water cement ratio for OPC aerated concrete mix for both mixes was adjusted in order to produce specimens which possess similar density as POFA cement based aerated concrete mix. Then, all specimens were demoulded after 24 hours before subjected to water curing for 28 days prior to immersing them into test solution as shown in Fig. 1. The durability performance of both OPC and POFA concretes were determined by measuring the loss of weights of the samples at different periods of immersion hydrochloric acid solution prepared using 0.3% hydrochloric acid having 99% concentration. The pH of the solution was controlled to about 2 throughout the immersion period of 1800 hours [Abdul Awal, 1998].

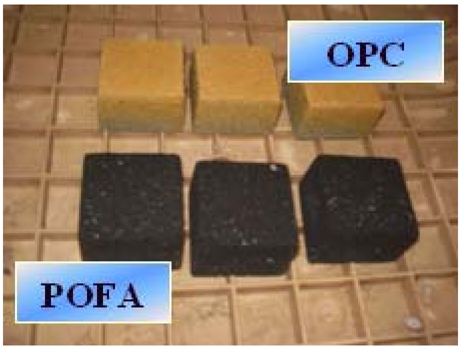

Figure 1. Specimens immersed in acid Hydrocloric solution.

2.3 Test For Sulphate Resistance

Data presented in this paper also include the durability performance of OPC aerated concrete acting as control and POFA cement based aerated concrete mortar bar immersed in 10% sodium sulphate solution. The procedure followed in conducting this test was in accordance with ASTM C1012-89. The design mix for OPC and POFA aerated concrete is similar to the design mix used for preparing cubes for acid test as mentioned above. Both samples either OPC or POFA were subjected to water curing for 28 days before immersed in the prepared sulphate solution. The performance of the specimens was evaluated in terms of expansion characteristic of mortar bars immersed in the sulphate solution. Figure 2 illustrates few mortar bars ready to be measured for the expansion. Data reported in this paper were the averages of six measurements for both mortar bars and cubes.

Figure 2. Mortar bar for Sulphate resistance test.

3 RESULTS AND DISCUSSION

3.1 Resistance to Acid Attack

The study on resistance to acid attack of aerated concrete cube specimens has been carried out by measuring the loss of weight of the samples continuously submerged in a 5% hydrochloric acid solution. Figure 3 reveals that aerated concrete with POFA exhibited better resistance towards the acid at all periods of immersion. Although both specimens begin to lose its weight as the period of immersion increased, percentage of weight loss for OPC cubes always higher than POFA specimen. In addition, the surface of OPC aerated concrete begins to soften and become loose. This fact has been highlighted by Zivica & Bajza [2001] whom mentioned that loss of mass is one of the signs of acidic attack, and crushing and dropping of material from concrete is one of the deterioration sign. By the end of the immersion period, OPC aerated concrete already loss 3.94% of its weight; POFA cement based aerated concrete on the other hand only loss 0.90%. It is interesting to note that surface of POFA cement based aerated concrete cube showed better surface condition than those with OPC aerated concrete in not only have considerable amount of surface softening but also faces loss of small particles on both surface and edges. Both visual observation and weight loss evidently analysis proves that POFA aerated concrete has higher resistance towards acid attack compared to control specimen.

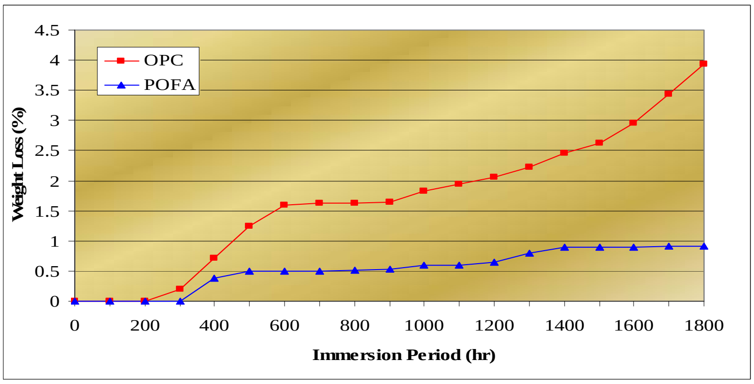

Figure 3. Comparative weight loss of OPC and POFA cement based aerated concrete specimens continuously immersed in Hydrocloric acid solution.

The better resistance of POFA specimen is expected not only because of the fact that POFA is being identified as a good pozzolanic material [Hussin & Abdul Awal, 1997] but also due to its low CaO content which is 4.24% in comparison to the high content of approximately 50% in OPC. Amount of

CaO presence in the binder material tend to play significant role in production of Calcium Hydroxide which is susceptible to acid attack finally leading to deterioration of hardened concrete material. This is because acid medium attacks mainly calcium hydroxide and then hydration products in cement matrix which leads to hydrolytic decomposition of hydration cement products followed by degradation of mechanical properties of cement based material [Zivica, 1999]. In addition, another researcher Mehta [1992] concludes that because of the higher content of CaO the hydration products of OPC contain about 25% CaOH which turns to be primarily responsible for the resistance of ordinary Portland cement exposed to acidic attack. As POFA contains a small amount of CaO, consequently the amount of CaOH would surely be less in the products of hydration.

3.2 Resistance to Sulphate Attack

Figure 4 shows the expansion patterns of POFA cement based aerated concrete and OPC specimen mortar bar throughout the immersion period in 10% Sulphate Solution. Basically, OPC aerated concrete bars had higher expansion value throughout the immersion period than that of POFA specimen bars. OPC mortar bar begin to exhibit significant expansion starting from 4th week when at the same time it was observed the development of crack at both end of the specimen. However, POFA specimen remains intact although there is slight expansion which is far lower than the control specimen. After 8 weeks of immersion period, it was noted that the expansion of OPC aerated concrete bar were 18.4 % having map cracks all over the specimens causing he mortar bars to disintegrate before measurement can be taken at the following week. On the other hand, POFA specimen bar expansion was as low as 1.92 % without any crack development on it. Elongation of OPC mortar bar compared to POFA specimen can be observed in Figure 5. It is justifiable for aerated concrete to exhibit significant expansion after four weeks exposed to Sulphate solution as compared to other types of concrete that been studied by Cao et.al [1997] and Abdul Awal [1998] that took more than 20 weeks for the specimens to exhibit similar pattern of failure as presented in this study. This is because aerated concrete which is a very porous material allows the sulphate solution to penetrate the internal structure of the material permitting fast response towards sulphate ion resulting in formation of cracks and elongation.

Discussing on the performance of OPC and POFA specimen, it is obvious POFA cement based aerated concrete mortar bar possess higher resistance towards Sulphate attack. Basically, the results obtained suggested that POFA as a partial cement replacement in aerated concrete could improve the sulfate resistance of this lightweight concrete. This is because according to Neville [1995] mortar or specimens having pozzolanic materials exhibit better chemical resistance that specimens with Portland cement due to the depletion of calcium hydroxide liberated during the hydration process, thereby reducing the amount of free calcium hydroxide for leaching and rendering the aluminium-beraing face inactive. Since POFA also a pozzolanic material, integrating it as partial cement replacement lead to reduction in the amount of C_3A, hence, all the aluminate bearing phases will accordingly be reduced. Basically, inclusion of POFA not only successfully reduce the amount of $Ca(OH)_2$ formed during the hydration of Portland Cement , which is susceptible to Sulphate attack but also the pozzolans presence reacted with the calcium hydroxide eventually reducing amount of $Ca(OH)_2$ that is susceptible to sulphate attack while at the same time producing a secondary calcium silicate hydrate (C-S-H).

Following that, the pozzolanic reactions contribute to space-filling process [Colak, 2003] whereby the secondary C-S-H formed were deposited in the pores making blended cement impermeable and therefore, the sulfate ions cannot easily penetrate through the concrete matrix which also become dense [Al-Amoudi, 2002]. Generally, addition of POFA not only decrease the amount of $Ca(OH)_2$ formed, but also contributed towards formation of concrete with lower permeability as a result of pozzolanic reaction that refines the pore structure and its capability to be filler because of its small particle size. This fact has been supported by Jaturapittakul et.al [2006] whom justified that use of POFA to replace Portland Cement not only decreases the $Ca(OH)_2$ content of hydrated cement but also serves as a filler and reduce voids between the aggregates and hydration products, leading to denser concrete.

On the other hand, OPC aerated concrete is susceptible to sulfate attacks due to its larger amount of $Ca(OH)_2$ and the condition of the pore structure which is bigger makes this highly permeable material possess lower resistance towards sulfate attack. The weakness of concrete consisting 100% OPC has been highlighted by Colak [2003] whom mentioned that the presence of Tricalcium Aluminate (C_3A) and Tetracalcium Aluminoferrite (C_4AF) contents in Portland Cement tend to react with sulfates to form ettringite which causes expansion and disintegration of the hardened Portland Cement pastes. As for the permeability aspect, Khatri and Sirivivatnon [1997] added that it is an important property that directly affects the durability of concrete against sulfate attack. This is because concrete with bigger pore structure due to existence of gaps among aggregates and hydrated product is more susceptible to penetration of sulfate because of its less permeable nature. In conclusion, it can be said that the lower amounts of calcium hydroxide in this agro blended cement based aerated concrete which also possess finer pore structure that reduce its permeability provides a considerable improvement in the durability of these composites towards sulphate attack.

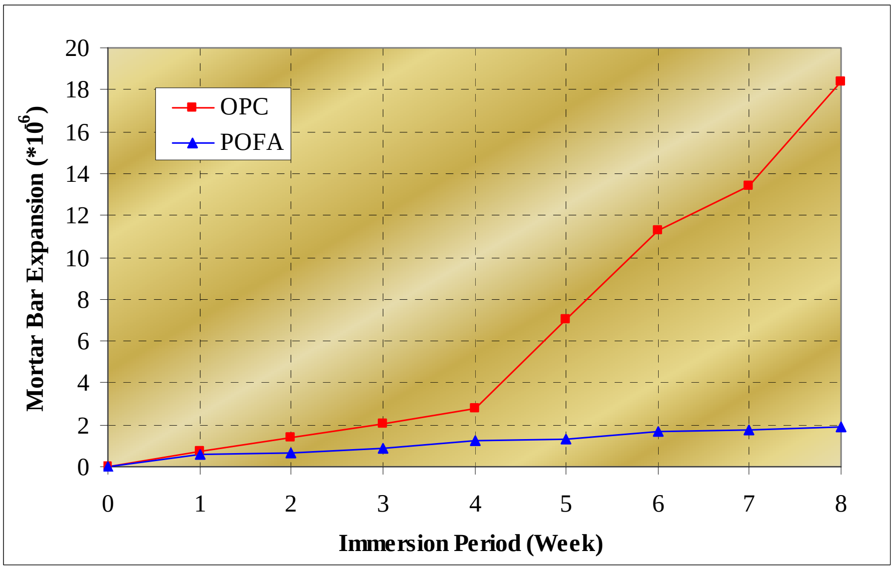

Figure 4. Expansion of OPC and POFA cement based aerated concrete mortar bar during the immersion period in 10% Sodium Sulphate solution.

Figure 5. OPC specimen expand more than POFA specimen.

3 CONCLUSION

The work presented in this paper indicates that both acid and sulphate resistance of aerated concrete improves with the integration of POFA as partial cement replacement material. Integration of POFA which possess very low content of CaO is responsible to produce lower amount of Calcium Hydroxide which is susceptible to both acid and sulphate attack. Therefore, inclusion of POFA in aerated concrete not only able to reduce Calcium Hydroxide formed in the first place but also able to make use of the available $Ca(OH)_2$ during pozzolanic reaction thus successfully refine the pore structure of agro blended cement based aerated concrete eventually producing a more impermeable matrix as compared to specimen consisting 100% OPC aerated concrete. Conclusively, POFA cement based aerated concrete which consist POFA with lower amount of CaO play important role to make this material be superior in terms of acid and sulphate resistance as compared to OPC aerated concrete.

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REFERENCES

Abdul Awal, A.S.M. & Hussin, M.W. 1996, ‘Properties of fresh and hardened concrete containing palm oil fuel ash’ Proceedings Of The 3rd Asia-Pacific Conference On Structural Engineering And Construction, Johor Bahru, Malaysia, 17th -19th June 1996, pp. 359-367.

Abdul Awal, A.S.M. 1998, ‘A study on strength and durability performances of concrete containing palm oil fuel ash’, University Teknologi Malaysia: PhD Thesis

Abdullah, K., Hussin, M.W., Zakaria, F., Muhammad, R., and Abdul Hamid, Z. 2006a, ‘POFA : a potential partial cement replacement material in aerated concrete’ Proceedings of the 6th Asia-Pacific Structural Engineering & Construction Conference, Kuala Lumpur, Malaysia Sept 5-6 2006.

Abdullah, K., Hussin, M.W., Zakaria, F., and Abdul Hamid, Z. 2006c, ‘Development in compressive strength of POFA cement based aerated concrete’, Proceedings of the 1st International Conference On Technology Management, Putrajaya, Malaysia Dec 4-5.

Arreshvhina, N. 2002, ‘Application of slag cement based aerated lightweight concrete in non-load bearing wall panels’ Universiti Teknologi Malaysia. Master Thesis

Annual Book of ASTM Standards, 1989, ‘Standard test method for length change of hydraulic-cement mortars exposed to a sulphate solution’ American Society of Testing And Materials, Philadelphia, ASTM C1012-89.

Cao, H.T., Bucea, L., Ray, A. and Yozghatlian, S. 1997, ‘The effect of cement composition and pH of environment on sulfate resistance of Portland cement and blended cements’, *Cement And Concrete Composites*, [19], pp 161-171.

Colak, A. 2003, ‘Characteristics of pastes from a Portland cement containing different amounts of natural pozzolan’, *Cement And Concrete Research*, [33], pp 585-593.

Hussin, M.W. & Abdul Awal, A.S.M. 1996, 'Influence of palm oil fuel ash on strength and durability of concrete', Proceedings Of The 7th International Conference On Durability Of Building Materials And Components, Stockholm, E & FN Spon, London, Vol.1, pp 291 – 298.

Hussin, M.W. & Abdul Awal, A.S.M. 1997, 'Palm oil fuel ash – a potential pozzolanic material in concrete construction', *Journal of Ferrocement*, **27**[4], 321- 327.

Khatri, R.P. & Srivivatnon, V. 1997, 'Role of permeability in sulphate attack', *Cement Concrete Research*, **27**[8], 1179-1189.

Mat Yahaya, F. 2003, 'Pengaruh abu terbang kelapa sawit terhadap kekuatan mampatan dan ketahanlasakan konkrit berudara', Universiti Teknologi Malaysia. Master Thesis.

Mehta, P.K. 1992, 'Rice husk ash – a unique supplementary cementing material' in *Advances In Concrete Technology*, CANMET, Ottawa, pp 407-431.

Neville, A.M. 1995, *Properties of Concrete*, Addison Wesley Longman Limited, England.

Sata, V., Jaturapitakkul, C. & Kiattikomol, K. 2004, 'Utilization of palm oil fuel ash in high-strength concrete', *Journal Of Materials In Civil Engineering*, [16], 623-628.

Zivica, V. & Bajza, A. 2001, 'Acidic attack of cement based materials – a review. art 1. principle of acidic attack', *Construction and Building Materials*, [15], 331-340.

Zivica, V. 1999, 'Acidic attack of materials based on the novel use of silica fume in concrete', *Construction and Building Materials*, [13], 263-269.

Al-Amoudi, O.S.B. 2002, 'Attack on plain and blended cement exposed to aggressive sulfate environments', *Cement & Concrete Composites*, [24], 305-316.